Copy No.
4

UNCLASSIFIED ~~CONFIDENTIAL~~

RM No. A7B03

C 2

CLASSIFICATION CHANGED 1947

~~RESTRICTED~~
~~SECURITY INFORMATION~~

NACA

authority of H. L. Dryden 1-16-52
per NACA Release form #769.
By HYR, 10-6-52.

RESEARCH MEMORANDUM

CLASSIFICATION CHANGED

To UNCLASSIFIED

By authority of H. L. Dryden Date 6-5-53
per NACA Release form #1419.
By HYR, 7-21-53

FLIGHT OBSERVATIONS OF AILERON FLUTTER AT HIGH MACH NUMBERS AS AFFECTED BY SEVERAL MODIFICATIONS

By

John R. Spreiter, George M. Galster,
and George E. Cooper

Ames Aeronautical Laboratory
Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
April 25, 1947

~~CONFIDENTIAL~~
~~RESTRICTED~~
UNCLASSIFIED
~~SECURITY INFORMATION~~

[redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

FLIGHT OBSERVATIONS OF AILERON FLUTTER AT HIGH MACH NUMBERS AS AFFECTED BY SEVERAL MODIFICATIONS

By John R. Spreiter, George M. Galster,
and George E. Cooper

SUMMARY

During dive tests of a typical fighter airplane, a type of aileron flutter occurred which was evidently associated with high-speed flight. At a Mach number of 0.745 the flutter was of such intensity that no further increases of Mach number were attempted. Data obtained during these tests show that, as the speed was increased from the lowest test speed, both ailerons floated upward progressively, reaching an angle of 0.8° at a Mach number of 0.72. With further increases of Mach number, to the highest test value of 0.745, the aileron angle rapidly increased to approximately 3° up, with the onset of flutter occurring at a Mach number of approximately 0.73. At Mach numbers between 0.735 and 0.745 the ailerons fluttered with a frequency of about 20 cycles per second and attained amplitudes as large as 3°. The onset of aileron flutter was shown to be a function of Mach number but was relatively independent of altitude, aerodynamic balance, and small changes of mass balance of the aileron.

UNCLASSIFIED [redacted] ~~RESTRICTED~~

[redacted] INFORMATION

[redacted]

When the aileron control system was modified by installing a hydraulic irreversible unit, the onset of aileron flutter was delayed to a Mach number of approximately 0.75 and the flutter amplitude never exceeded 1°, which was of the same magnitude as the play in the irreversible aileron control system. The flutter frequency was again about 20 cycles per second. Due to small amounts of creep in the irreversible units, both ailerons floated up as the critical Mach number was exceeded, although the magnitude of this upfloat was considerably less than that experienced with the normal control system.

Analysis of the available data indicates that the upfloating tendency observed at Mach numbers greater than 0.72 is due to the shock-induced separation on the upper surface being greater than that on the lower surface. The aileron flutter appears to be a separate phenomenon caused by a coupling of the variations of the positions and intensities of the shock waves with the aileron motion. This coupling promotes an aileron flutter which requires but one degree of freedom, aileron rotation.

INTRODUCTION

A type of aileron flutter, apparently associated with high-speed flight, has been reported to occur on several airplanes while flying at high subsonic airspeeds. One of the earliest encounters with this particular type of flutter was experienced in a fighter airplane during high Mach number dives

[redacted]

being conducted at the Ames Aeronautical Laboratory. On this occasion the aileron flutter began at a Mach number of 0.73 and became so intense at a Mach number of 0.745 that further increases of airspeed were considered unsafe. The purpose of the investigation reported herein was to provide information concerning the effect of certain airplane parameters on the occurrence and intensity of this flutter phenomenon. Accordingly, in subsequent flights, chordwise pressure distributions were measured at one wing station, and the effects of varying the indicated airspeed, altitude, and mass and aerodynamic balance of the ailerons were observed. Furthermore, a hydraulic irreversible unit was installed in the aileron control system in order to investigate the effect of this modification upon the flutter phenomenon. Since the installation of such a unit in the control system alters the flying qualities of an airplane, comments relative to handling characteristics of the airplane are included in an appendix.

DESCRIPTION OF AIRPLANE

The airplane utilized in this investigation is a single-place, single-engine, low-wing, cantilever monoplane. A three-view drawing of the airplane showing the spanwise station at which the wing pressure distribution was obtained is shown in figure 1. Figure 2 shows a photograph of the airplane as instrumented during the flight tests. A sectional view of the airfoil at the pressure-distribution station showing the aileron section, balance, and seal, is presented in figure 3. Since the only change in airfoil and aileron section along the aileron span is a slight change in camber, this view may be considered typical of the entire wing-aileron combination. The general specifications of the wing and aileron combination are as follows:

Wing

Span	38 ft 4 in
Area	248 sq ft
Aspect ratio	5.93
Taper ratio	2:1
Incidence, root	1.30°
Incidence, tip	-0.45°
Dihedral (top surface 35-percent chord)	3.67°
Sweepback (leading edge)	5.10°
M.A.C.	6.88 ft
Airfoil root	NACA 66,2X-116 (a = 0.6)
Airfoil, tip	NACA 66,2X-216 (a = 0.6)

Ailerons

Span (along hinge line, each)	10.063 ft
Area aft of hinge line, each	8.143 sq ft
Fixed balance area, each	4.826 sq ft
Mass overbalance, each	2.7 in-lb
Travel	±15°

The aileron control system was of the push-pull rod type. The variation of aileron deflection with hinge moment, as measured in static ground tests with the control stick locked, is shown in figure 4.

The original aileron control system was modified for a portion of the tests by installing an irreversible unit on the rear spar of the wing 2 feet inboard from each aileron bell crank. A photograph of the installation is shown in figure 5. This mechanism, designed and constructed at the Ames Aeronautical Laboratory, operates on the hydraulic-lock principle, the relief valves being actuated only by motions of the control stick. Due to imperfect fluid seals, this mechanism could not completely lock the ailerons; an applied aileron hinge moment of 10 foot-pounds caused the aileron to creep approximately 7° per minute. In addition, it was possible to move the ailerons approximately 1° without transmitting the motion past the irreversible unit. This movement was traced to backlash in the rod-end bearings and the hydraulic unit, and to distortion of the rear spar web supporting the bell crank. The total friction in the aileron control system with irreversible units installed on both ailerons was equivalent to a control force of approximately 6 pounds.

INSTRUMENTATION

Standard NACA photographically recording flight instruments were used to measure, as a function of time, the following variables: indicated airspeed, pressure altitude, normal acceleration, control force, rolling velocity, aileron position, and chordwise pressure distributions at a wing station 8 feet 3 inches from the left wing tip. In early tests only the motions of the left aileron were recorded; whereas in later flights the motions of both ailerons were recorded. The aileron position recorders were tested to determine their fidelity in recording high-frequency motions and were found capable of recording both the correct amplitude and frequency at rates to at least 30 cycles per second, the highest frequency tested. Both recorders were connected directly to the ailerons.

A swiveling pitot-static tube, used for the measurement of airspeed, was mounted on a boom extending 8 feet ahead of the wing leading edge and located 2 feet inboard of the right wing tip. The installation was calibrated for position error. Indicated airspeed as used in this report is defined by the usual formula by which standard airspeed meters are calibrated. (See reference 1.)

RESULTS AND DISCUSSION

The data for the present report were obtained during dives starting at various altitudes. Typical time histories are presented in figure 6 illustrating the aileron flutter encountered with four different configurations: (1) with production ailerons, (2) with the left aileron mass-underbalanced 2.0

inch-pounds, (3) with the aileron pressure seals removed and the ailerons mass-balanced the same as originally (2.7 in-lb mass-overbalanced), and (4) with irreversible units installed in the aileron control system and with the ailerons having the same mass and aerodynamic balance as the production ailerons. In the following discussion the first three configurations will be referred to simply as the normal control system.

Although the time histories for the normal control system (figs. 6(a), 6(b) and 6(c)) show that the flutter amplitude was the least when the left aileron was mass-underbalanced and the greatest when the pressure seals were removed, these variations in flutter amplitude may also be correlated with the variations of Mach number since the greater amplitudes always occur at the higher Mach numbers.

Further analysis of the time histories for the normal control system (figs. 6(a) through 6(c)) indicates that the aileron flutter phenomenon was characterized by the following sequence of events. As the Mach number was increased beyond 0.72 both ailerons started floating upward. At a Mach number of about 0.73, an incipient aileron flutter occurred, which at a slightly higher Mach number developed a steady frequency of about 20 cycles per second; further increases of Mach number up to 0.745 resulted only in a greater amplitude of the vibrations. Despite changes of indicated airspeed from 365 to 460 miles per hour, both the onset and the disappearance of flutter always occurred at a Mach number of about 0.73.

While this observation is interpreted as indicative of the fact that the flutter phenomenon is independent of indicated airspeed, insofar as this variable affects either the forces involved or the true airspeed (of importance in classical flutter), it is considered that the lift coefficient range covered by variations of either indicated airspeed or normal accelerations was insufficient to arrive at a conclusion regarding the effect of lift coefficient. Data for another airplane (reference 2) show a definite relationship between the lift coefficient and the Mach number corresponding to the onset of flutter; as the lift coefficient increased from 0 to 0.80, the Mach number at which flutter occurred decreased from 0.790 to 0.705.

With the irreversible aileron control system, three dives were made to the point of severe airplane buffeting during the course of one flight. At the conclusion of this flight, it was discovered that a large amount of play had been produced in the bell-crank bearings and the aileron attachment fittings. Consequently, it was not considered safe to continue the flight tests and no further development of irreversible aileron control systems was attempted.

Records taken during the tests with the irreversible control system (fig. 6(d)) show that the same upfloating tendency appeared prior to the flutter as was noted with the normal control system. The onset of flutter, however, was postponed to a Mach number of 0.75 and the amplitude was limited to less than a degree. It should be noted that this

[redacted]

flutter amplitude (approximately 1°) corresponds roughly to the amount of play in the irreversible aileron control system. While the test irreversible control system failed to prevent completely the aileron upfloat and flutter, it is felt that their occurrence was the result of deficiencies in the irreversible control system. Were a completely irreversible control system installed, it is believed that no flutter nor upfloat would occur. This belief is substantiated by the fact that the rigidly held landing flaps were never reported to flutter.

The variation with Mach number of the aileron angles measured in straight flight with the normal control system is shown in figure 7. These data show that at Mach numbers greater than 0.72, the effects of moderate changes of altitude, indicated airspeed, or aileron configuration are small in comparison with those of Mach number. Similar data for the irreversible control system are not presented because, due to creep, the aileron angle is a function of the time rate of change of Mach number as well as of the Mach number itself. Insufficient data are available to present adequately this more complicated relationship. The time history of figure 6(d) does show, however, that the ailerons float upward in a manner quite similar to that indicated in figure 7 for the normal control system.

Chordwise pressure distributions recorded 1 and 4 seconds after the start of the time history shown in figure 6(b) are

[redacted]

[redacted]

presented in figure 8 to show typical distributions before and during the occurrence of aileron flutter. Because of the damping and inertia in the pressure lines between the orifices in the wing and the manometer in the tail compartment of the fuselage, the pressure distribution recorded while the aileron was fluttering is somewhat inaccurate, but it does have significance as a mean pressure distribution.

Relation Between Aileron Upfloat and Flutter

It appears from an analysis of the flight data in conjunction with the critical Mach number data, presented in figure 9, that the upfloating tendency and the flutter are the result of two relatively independent, but related, phenomena. Before examining these phenomena in detail, a discussion of figure 9 will be presented.

The critical Mach numbers of both the upper and lower surfaces of the NACA 66,2-216 $(a = 0.6)$ airfoil with a 15-percent-chord plain flap, which is very similar to the airfoil and aileron combination of the test airplane, were computed for several flap deflections by the method of reference 3 and plotted as a function of lift coefficient. In order to adjust for the difference between theory and actuality, several test points obtained from the experimental pressure distributions are presented and new curves of critical Mach number for the test airplane wing are estimated on the basis of both the theoretical and experimental results and are shown in figure 9

[redacted]

by dotted lines. The relation between the critical Mach number of the airfoil section (as presented in fig. 9) and the aileron upfloat is shown in the following discussion.

An analysis of the variation of aileron angle with Mach number (fig. 7) in relation to the elastic characteristics of the normal control system (fig. 4) shows that as the Mach number increases from 0.30 to 0.72 at an altitude of 10,000 feet, the aerodynamic hinge moment applied on the left aileron increases from 3.0 to 13.5 foot-pounds, corresponding to hinge-moment coefficients of 0.005 and 0.004, respectively. The relative constancy of the hinge-moment coefficient at Mach numbers less than 0.72 indicates that the gradual upfloating of the ailerons in this range is essentially a function of dynamic pressure rather than an effect of compressibility.

With further increases of Mach number to 0.74, however, the mean aileron hinge moment increases rapidly to approximately 50 foot-pounds, which, at an altitude of 10,000 feet, corresponds to a hinge-moment coefficient of approximately 0.015. Because of the marked change in the hinge-moment coefficient and because the ailerons with the normal control system always start their pronounced upward movement at approximately the same Mach number, it is concluded that the upfloating tendency at Mach numbers above 0.72 is due mainly to an effect of compressibility.

The data of figure 9 show that for positive lift coefficients and for negative aileron angles up to 4°, the critical Mach number of the upper surface is always less than that of the lower surface. As a result, the magnitude of the shock-induced separation on the upper surface will probably be greater than that on the lower surface. Therefore, since the pressure coefficients on the rear portion of an airfoil on which the flow is separated from the surface are more negative than they would be without separation, the ailerons would tend to float upward as the critical Mach number is exceeded. The actual amount of upfloat would be determined by the degree of separation and by the elasticity of the control system.

While the foregoing discussion indicates that the upfloating tendency at high Mach numbers is mainly the static consequence of the intensity of the shock-induced separation on the upper surface being greater than that on the lower surface, it is thought that the aileron flutter is a separate phenomenon resulting from a coupling of the variations of the positions and intensities of the shock waves with the aileron motions. As the aileron moves from its mean position during the occurrence of flutter, the relative intensities of the shock-induced separation on the upper and lower surfaces change, producing hinge moments tending to return the aileron to its mean position. Since a finite time is required for the aileron deflection to affect the flow over the wing, the restoring moments lag the aileron motions. It is possible, therefore, to have a component of the restoring moment in phase with the aileron velocity, promoting the continuance of an aileron flutter which requires but one degree of freedom, aileron rotation. Shadowgraph pictures[1] taken in the Ames 16-foot high-speed wind tunnel have confirmed the foregoing hypothesis in that they show a coupling between the shock-wave position and the aileron angle.

In contrast to the classical flutter problem, in which the aileron flutter is greatly affected by the values of the aerodynamic coefficients and the amount of mass balance of the ailerons, it appears that in a flutter phenomenon of the type just described the flutter would be relatively independent of variations of the dynamic and aerodynamic characteristics of the ailerons, provided the ailerons remain free to rotate. Such independence is in accord with the experimental data presented in this report. If the ailerons were not free to rotate, however, as would be the case with a perfect irreversible control system, it is believed that the flutter would not occur and the fluctuations of the hinge moments would be greatly reduced.

CONCLUSIONS

The following conclusions regarding aileron flutter were drawn from an analysis of the data obtained from dive tests of a fighter airplane:

---

[1] Data on file at this Laboratory.

1. With the normal control system, both ailerons floated upward progressively as the speed was increased reaching an angle of 0.8° at a Mach number of 0.72. With further increases of Mach number to 0.745, the deflections of both ailerons rapidly increased to 3° up, and the flutter started at a Mach number of approximately 0.73.

2. With the aileron control system modified by the installation of a hydraulic irreversible unit the flutter was delayed to a Mach number of about 0.75. This system was not completely irreversible; however, backlash and distortion permitted about 1° of aileron deflection, and fluid leakage allowed the ailerons to creep slowly under applied hinge moments. Because of this creep, an upfloating tendency of the ailerons was still observed, although it was smaller than that measured with the normal control system. The amplitude of the flutter, less than 1°, was of the same magnitude as the play in the irreversible aileron control system.

3. The flutter frequency was approximately 20 cycles per second for all configurations tested.

4. The onset of aileron flutter was a function of Mach number but was relatively independent of altitude, aerodynamic balance, and small changes of mass balance of the aileron.

5. Analysis of the available data indicates that the upfloating tendency observed at Mach numbers greater than 0.72 is due to the shock-induced separation on the upper surface being greater than that on the lower surface. The aileron

flutter is a separate phenomenon caused by a coupling of the variations of the positions and intensities of the shock waves with the aileron motion. This coupling promotes an aileron flutter which requires but one degree of freedom, aileron rotation.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif.

John R. Spreiter,
Aeronautical Engineer.

George M. Galster,
Aeronautical Engineer.

George E. Cooper,
Engineer-Test Pilot.

Approved:

John F. Parsons,
Aeronautical Engineer.

APPENDIX

PILOTS' OPINIONS OF THE HANDLING QUALITIES OF THE AIRPLANE WITH IRREVERSIBLE AILERON CONTROL SYSTEM

While it appears that an irreversible aileron control system may offer one solution to the flutter problem, the lack of positive stick-free lateral stability and the added friction usually associated with irreversible mechanisms are undesirable features from the pilots' viewpoint. To determine the degree of acceptability of such control characteristics, the test airplane with the irreversible aileron control system installed was flown by several experienced test pilots and their opinions of the lateral stability and control characteristics were noted after each flight. These comments have been analyzed and are summarized herein together with representative quantitative aileron control-force data obtained in abrupt rolls.

Figure 10 shows a typical time history of an abrupt rudder-locked aileron roll of the test airplane with the irreversible aileron control system installed. This time history clearly shows the initial control force required to move the ailerons and to start the roll. Once the desired aileron deflection was reached, the control force was reduced nearly to zero, while the irreversible unit maintained the aileron at an effectively constant setting.

From the standpoint of the pilots, as judged from their comments, the undesirable characteristics of the test irreversible aileron control system were the high control friction and the feeling of stick-free neutral lateral stability. These characteristics were most noticeable and disagreeable during take-off and landing. For take-off, they reported that the ailerons must be neutralized by position alone, since it was impossible to determine whether or not they were neutralized until the airplane was airborne and the rolling moment caused by unbalanced ailerons caused a wing to drop. The wings could be kept level only by visual reference to attitude. Without devoting too much attention to attitude, corrective action was not applied by the pilot as soon as would be the case if he felt positive stick-free lateral stability, producing a definite tendency towards overcontrolling. This tendency, the pilots noted, gradually diminished as the speed was increased until, at speeds above about 250 miles per hour, it was possible to avoid overcontrolling by moving the ailerons with slow steady pressures instead of rapid movements. As the speed was decreased for landing, the overcontrolling tendency arose again and was even more noticeable than on take-off, because more corrections were usually necessary in making the approach at low speed. Rough air greatly aggravated the overcontrolling tendencies. The application of the slow steady stick pressures that reduced the overcontrolling tendencies at high speeds was practically impossible at low speeds due to the large aileron deflections required to produce the necessary restoring moment.

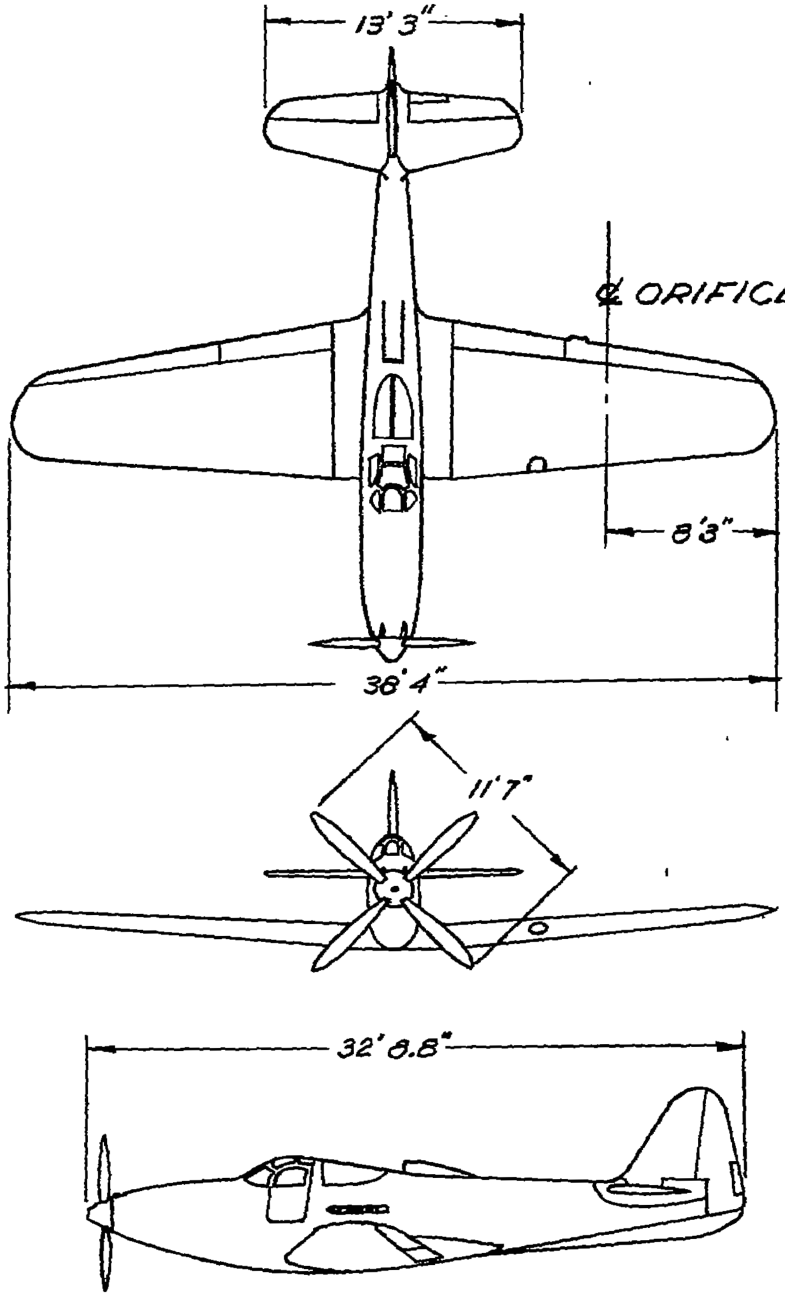
REFERENCES

1. Beij, K. Hilding: Aircraft Speed Instruments. NACA Rep. No. 420, 1932.

2. Brown, Harvey H., Rathert, George A. Jr., and Clousing, Lawrence A.: Flight-Test Measurements of Aileron Control Surface Behavior at Supercritical Mach Numbers. NACA RM No. A7A15, 1947.

3. Heaslet, Max. A., and Pardee, Otway O'M.: Critical Mach Numbers of Thin Airfoil Sections with Plain Flaps. NACA ACR No. 6A30, 1946.

CONFIDENTIAL



NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

FIGURE 1.- THREE VIEW DRAWING OF TEST AIRPLANE.

CONFIDENTIAL

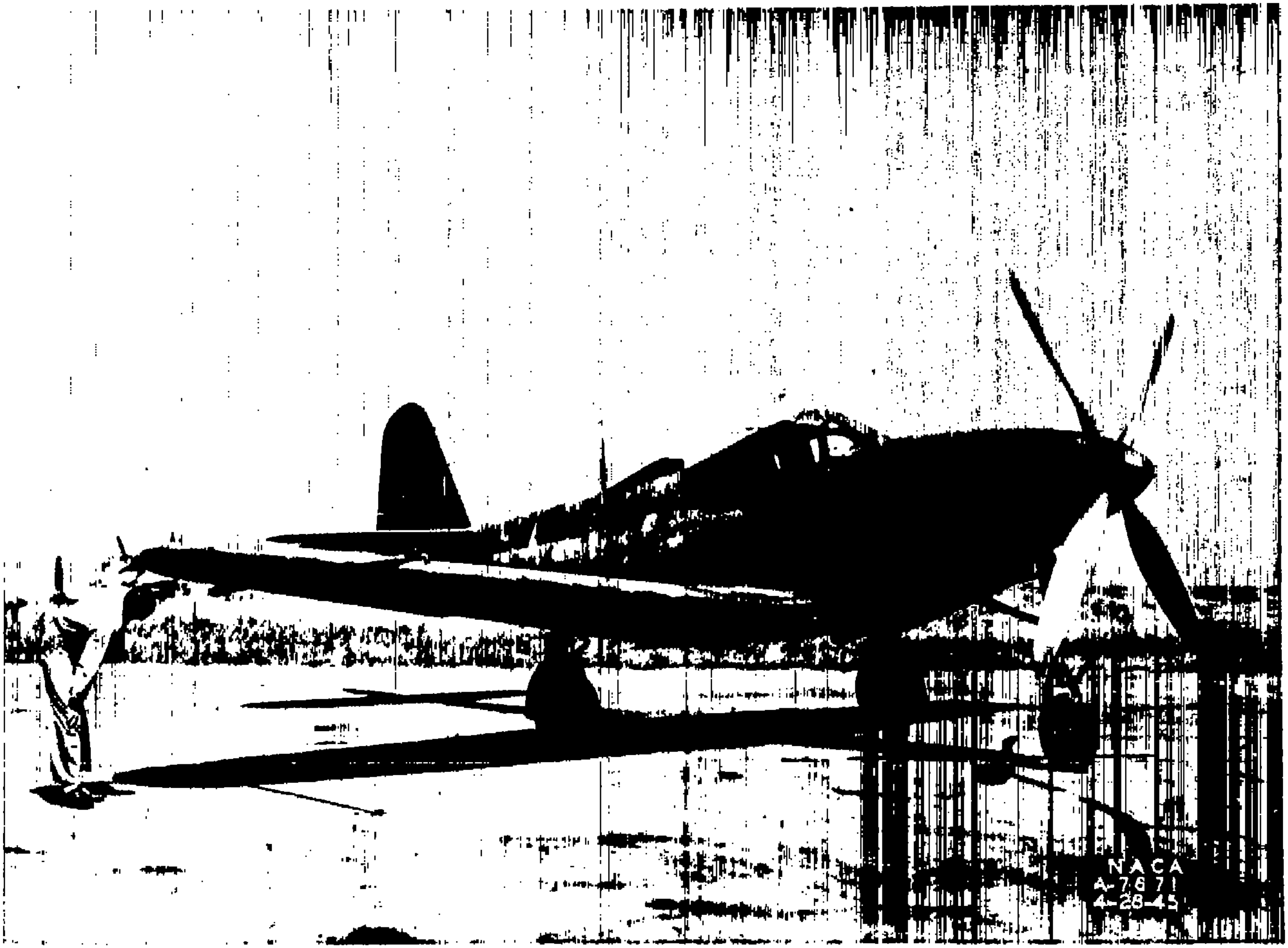


Figure 2.- The test airplane as instrumented for the flight tests.

[redacted]

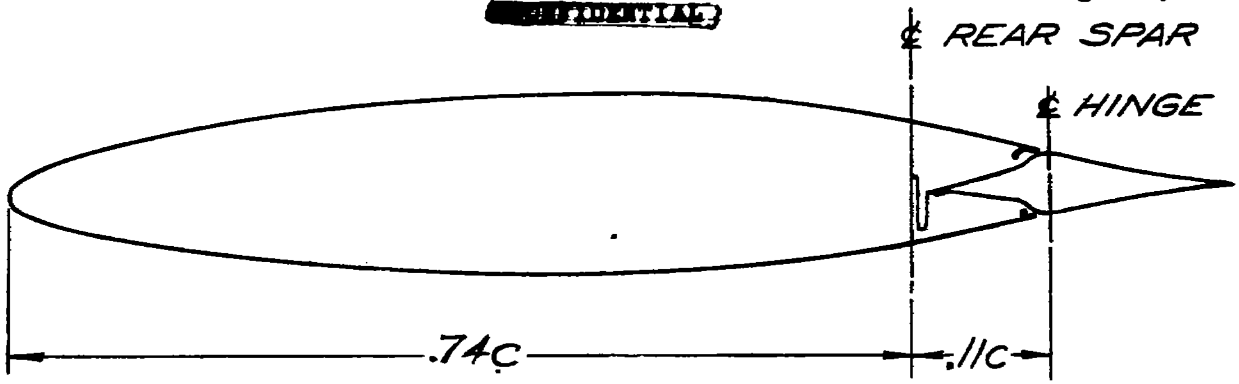


FIGURE 3. – CROSS SECTION OF WING AND AILERON.

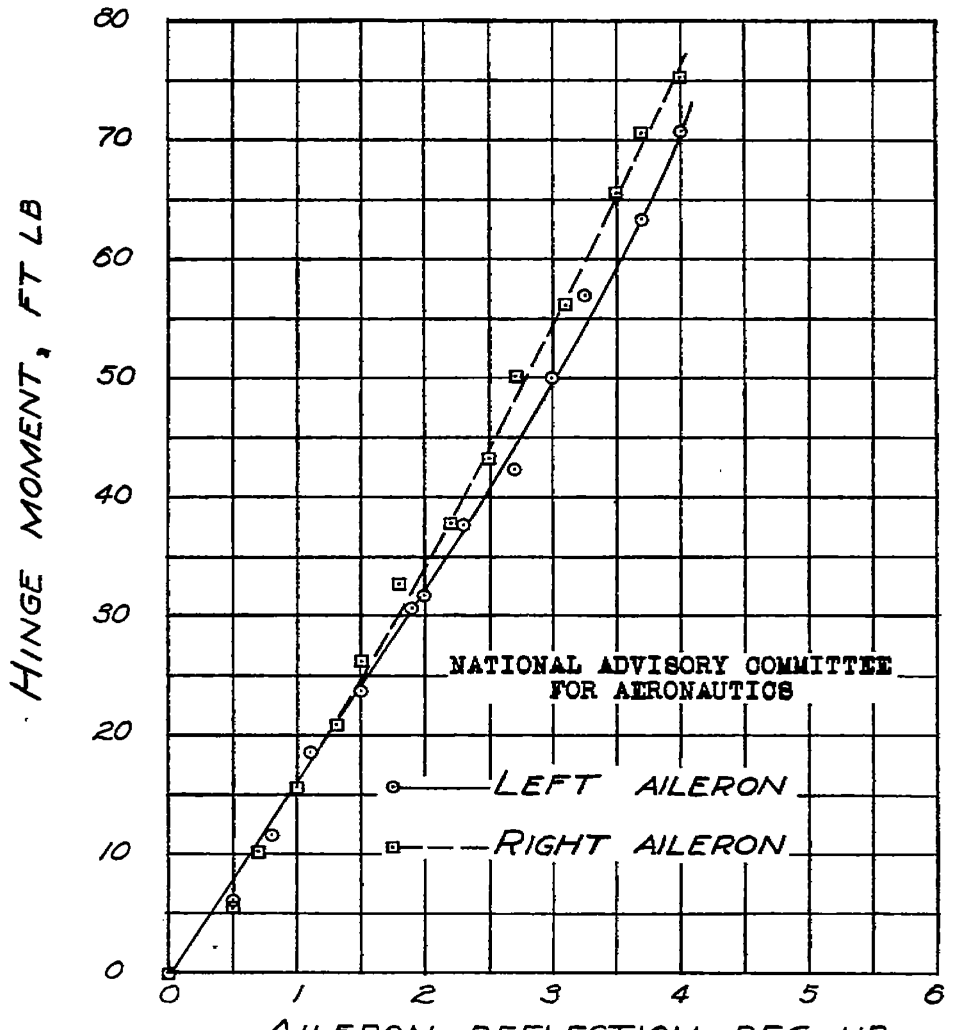


FIGURE 4 – VARIATION OF AILERON DEFLECTION WITH AILERON HINGE MOMENT WITH CONTROL STICK LOCKED. NORMAL CONTROL SYSTEM.

[redacted]

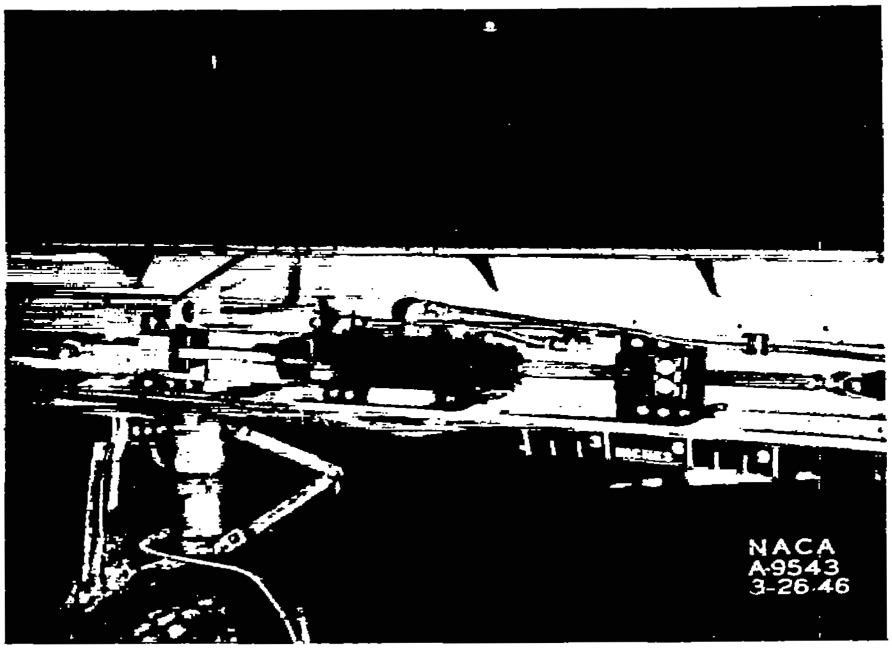
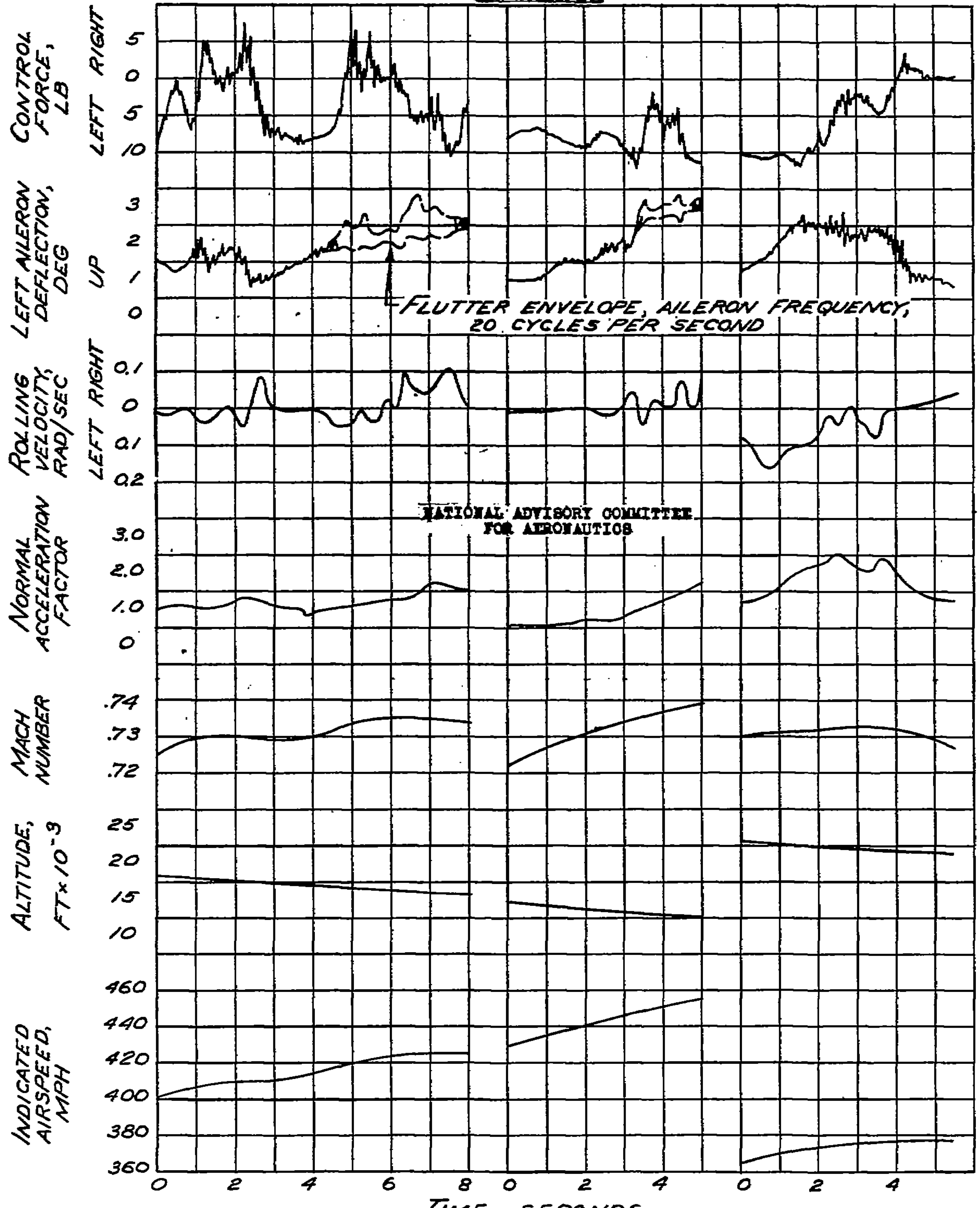


Figure 5.- The irreversible unit, as installed on the test airplane.



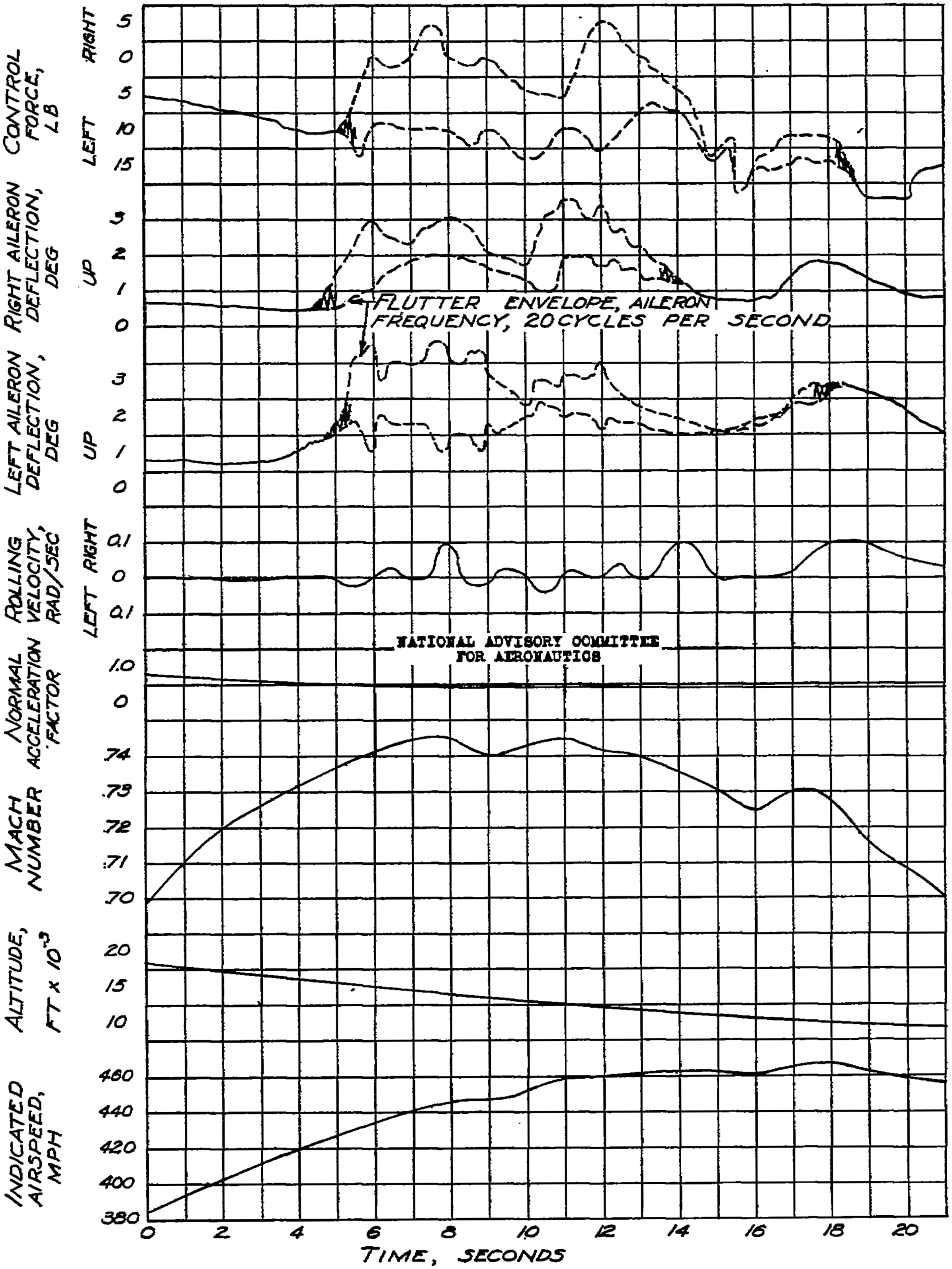
a.-PRODUCTION CONFIGURATION RUN 1

a.-PRODUCTION CONFIGURATION RUN 2

b.-LEFT AILERON 2.0 IN LB UNDER-BALANCE

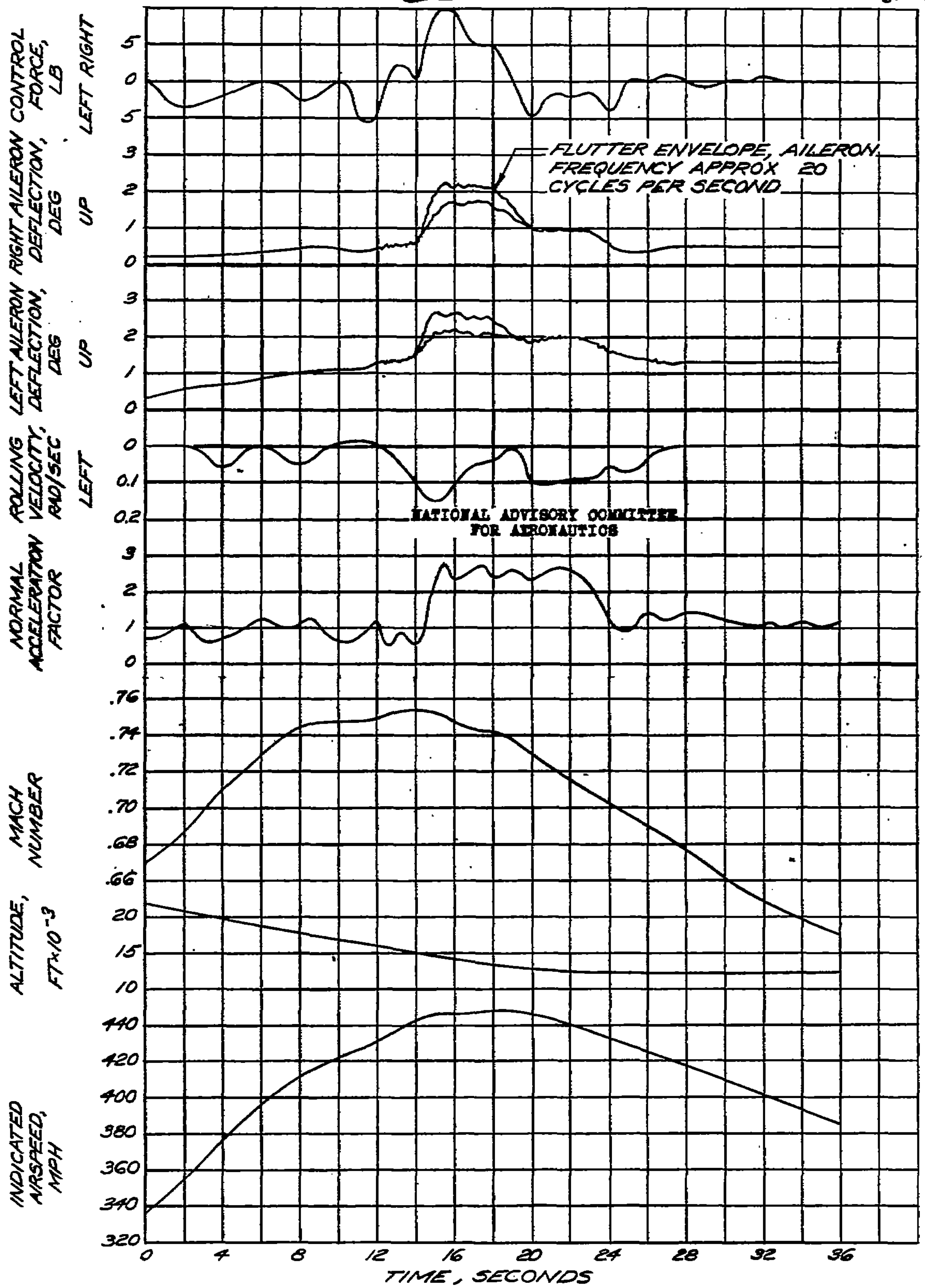
FIGURE 6. - TIME HISTORIES OF TYPICAL AILERON FLUTTER.

[redacted]



c.- AILERON SEALS REMOVED, AILERONS 2.7 IN. LB OVERBALANCE

FIGURE 6.— CONTINUED.- TIME HISTORIES OF TYPICAL AILERON FLUTTER.



d.– IRREVERSIBLE AILERON CONTROL SYSTEM

FIGURE 6.– CONCLUDED. TIME HISTORIES OF TYPICAL AILERON FLUTTER.

[redacted]

[redacted]

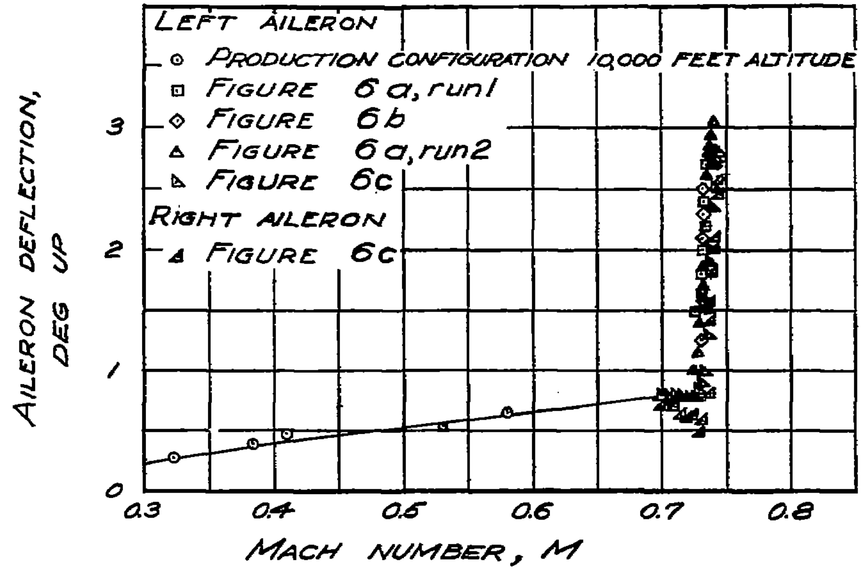


FIGURE 7.– VARIATION OF AILERON FLOATING ANGLE WITH MACH NUMBER IN STEADY FLIGHT. NORMAL CONTROL SYSTEM.

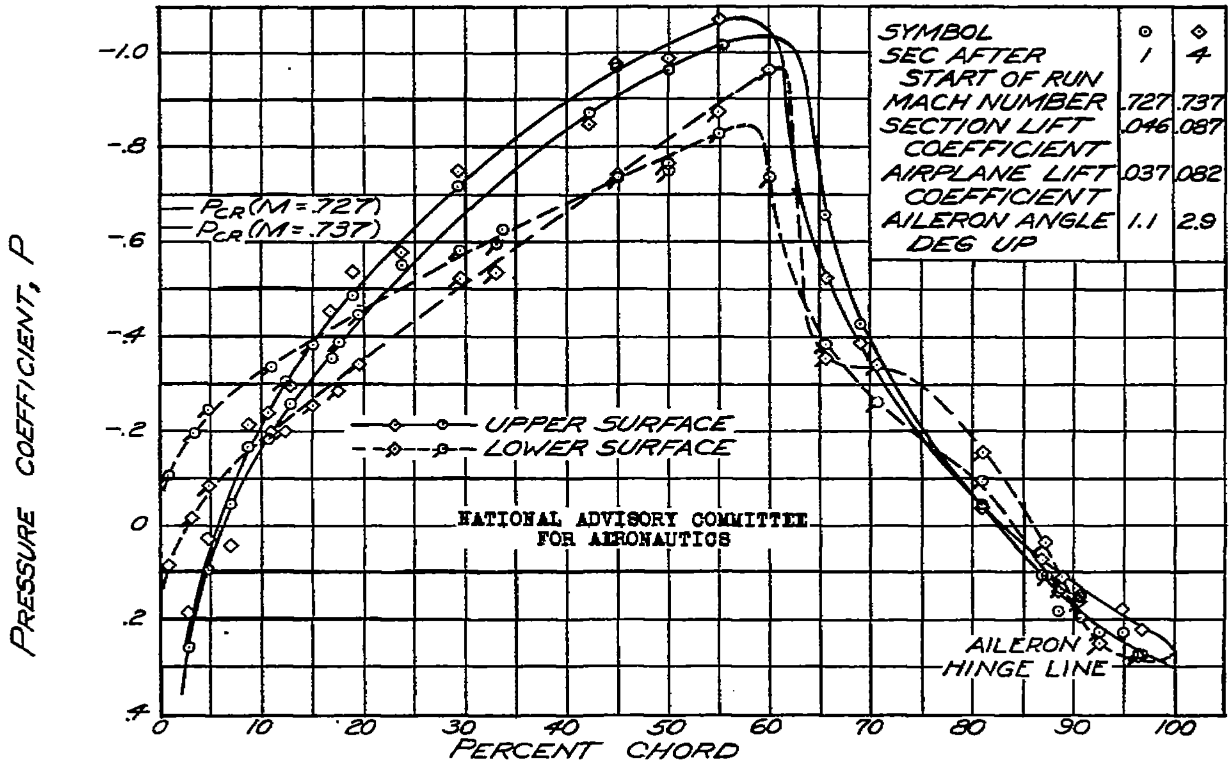


FIGURE 8.– TYPICAL PRESSURE DISTRIBUTIONS BEFORE AND DURING AILERON FLUTTER CORRESPONDING TO THE DATA SHOWN IN FIGURE 6(a) RUN 2.

[redacted]

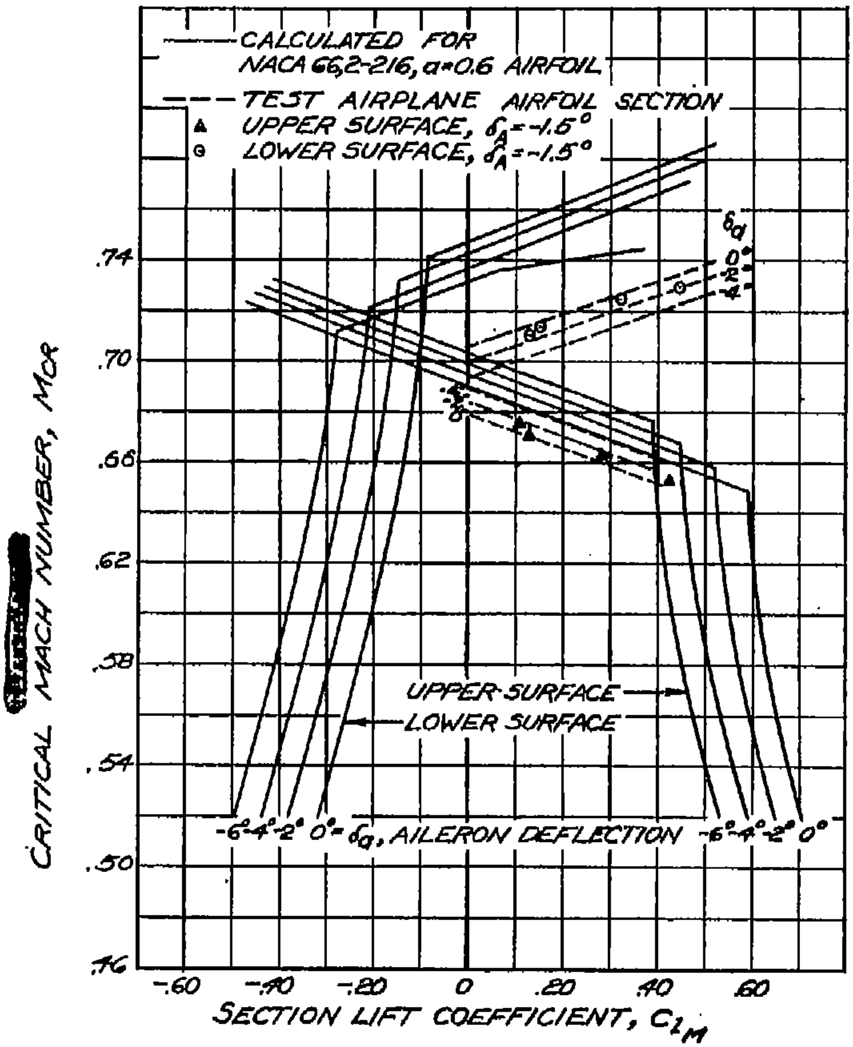
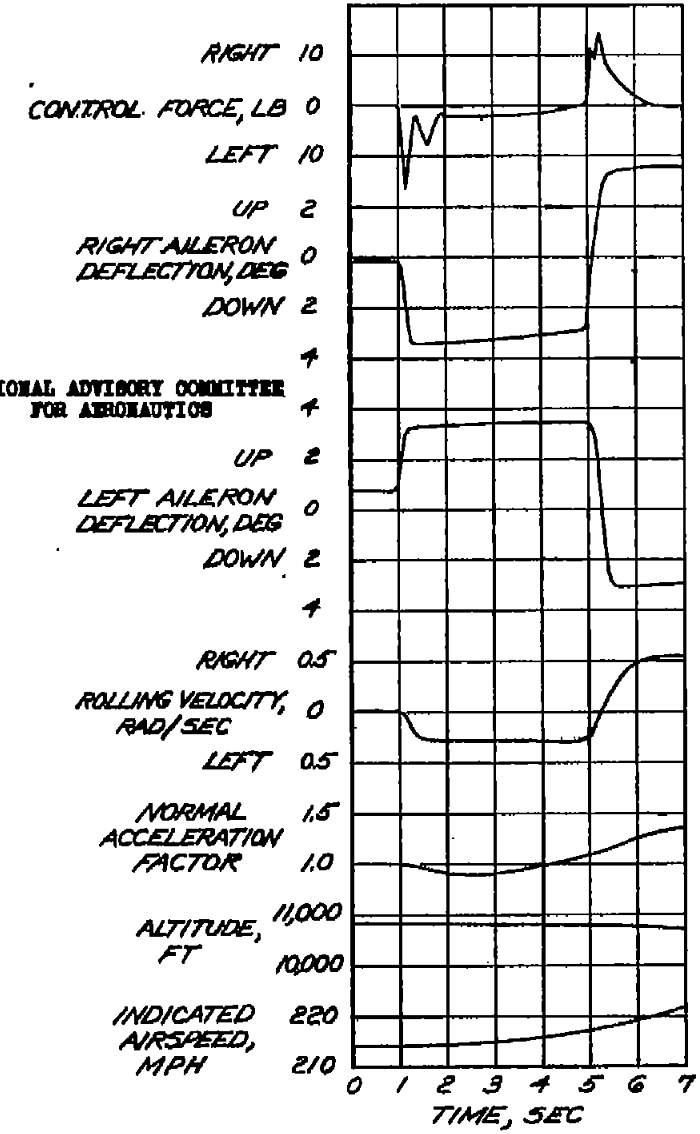


FIGURE 9.- VARIATION OF CRITICAL MACH NUMBER WITH HIGH-SPEED LIFT COEFFICIENT FOR VARIOUS AILERON DEFLECTIONS. NACA 66,2-216, a=0.6 AIRFOIL SECTION WITH 0.15C PLAIN FLAP AND THE TEST AIRPLANE AIRFOIL SECTION.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

FIGURE 10.- TIME HISTORY OF TYPICAL ABRUPT AILERON ROLL. IRREVERSIBLE AILERON CONTROL SYSTEM.